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Semi Annual Report
of the Work of the
Bartol Research Foundation of The
Franklin Institute
Performed under Contract [illegible]
June 3[illegible], [illegible] - [illegible], [illegible]

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SEMI ANNUAL REPORT

of the Work of the

BARTOL RESEARCH FOUNDATION

OF THE FRANKLIN INSTITUTE

(June 30, 1952 -- January 31, 1953)

Performed Under Contract Nonr 436(00)

with the

OFFICE OF NAVAL RESEARCH

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R. W. Gunnett

*Terminated employment

I. INELASTIC SCATTERING.

The progress of inelastic scattering measurements at this laboratory has been outlined previously in several reports and publications[1-4]. The present data constitute

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1) Interim Technical Report to Project NEPA, released September, 1950, later appearing in part as "The Scattering of Fast Neutrons by Bismuth and Lead", Mandeville and Swann, Phys. Rev. 84, 214 (1951).

2) Final Report of the Work of the Bartol Research Foundation of the Franklin Institute to Project NEPA as Performed under Contract 80-2034, issued April 30, 1951.

3) First Semi-Annual Report of the Work of the Bartol Research Foundation of the Franklin Institute Performed under Contract Nonr-436(00), issued December 31, 1951. Part of this report later was published as "The Scattering of Fast Neutrons by Wolfram", Mandeville, Swann and Seymour, Phys. Rev. 86, 861 (1952).

4) Status Report, Contract Nonr-436(00), January - September, 1952, submitted September 24, 1952.

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an extension of the earlier efforts. To date, the principal detector has been the photographic plate. Earlier measurements[1, 3] consisted in obtaining data with and without scatterers before the photographic plates. A disadvantage of the geometry was that primary unscattered neutrons could reach the plates along with the elastically and inelastically scattered neutrons giving rise to a large and undesirable background. This difficulty was summarized in the final report under Contract SC-2034 to project NEPA[2], April 30, 1951. In this same report it was also suggested that a geometry be adopted wherein the photographic plates would not be in the beam of primary neutrons incident upon the scatterer, that they should be located at 90° to the beam to receive neutrons scattered through that angle. Such a geometry was indicated in Figure 2 of Reference 2. A "90-degree" geometry was adopted by Stelson and Preston[5]

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5) Stelson and Preston, Phys. Rev. 86, 132 (1952).

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when they studied the neutron groups relating to the inelastic scattering of fast neutrons by iron[5].

Although the data of Stelson and Preston[5] were statistically poor, their results seemed to hold promise. Accordingly the large paraffin collimator of their measurements was constructed as described in Reference 4. In actuality, two collimators were prepared at Bartol, one of length

50 cm as initially built by Stelson and Preston, the other a shorter and more widely flared version of length 20 cm. The shorter collimator was cast to increase the neutron intensity at the scatterer. Objections have been raised in various quarters to the Stelson-Preston experiment. It has been argued that the presence of such large quantities of paraffin as they used, leads to a degradation of the primary neutron energy and to spurious groups of low energy neutrons which might be interpreted as having been inelastically scattered. Consequently, before doing any collimator experiments, it was decided to investigate some different variations of the so-called "wedge" geometry for shielding the photographic plates. A schematic diagram of one form of this geometry was given in Figure 1 of Reference 4. To keep scattering materials at a minimum, it was decided to irradiate a scatterer of iron in the geometry of Figure 1 of the present paper. This arrangement represents the extreme case in which there is no collimation or shielding to give any degradation of the primary neutron beam.

The desirable neutrons which are detected in the plates of Figure 1 are those which have proceeded from the deuterium target to the scatterer and thence through an angle of 90^0 to the photographic plates. Present also are recoil protons produced by irradiation of the photographic plates by the neutrons arriving directly from the target. In the measurement of the plates, only the upper half of the plates, the

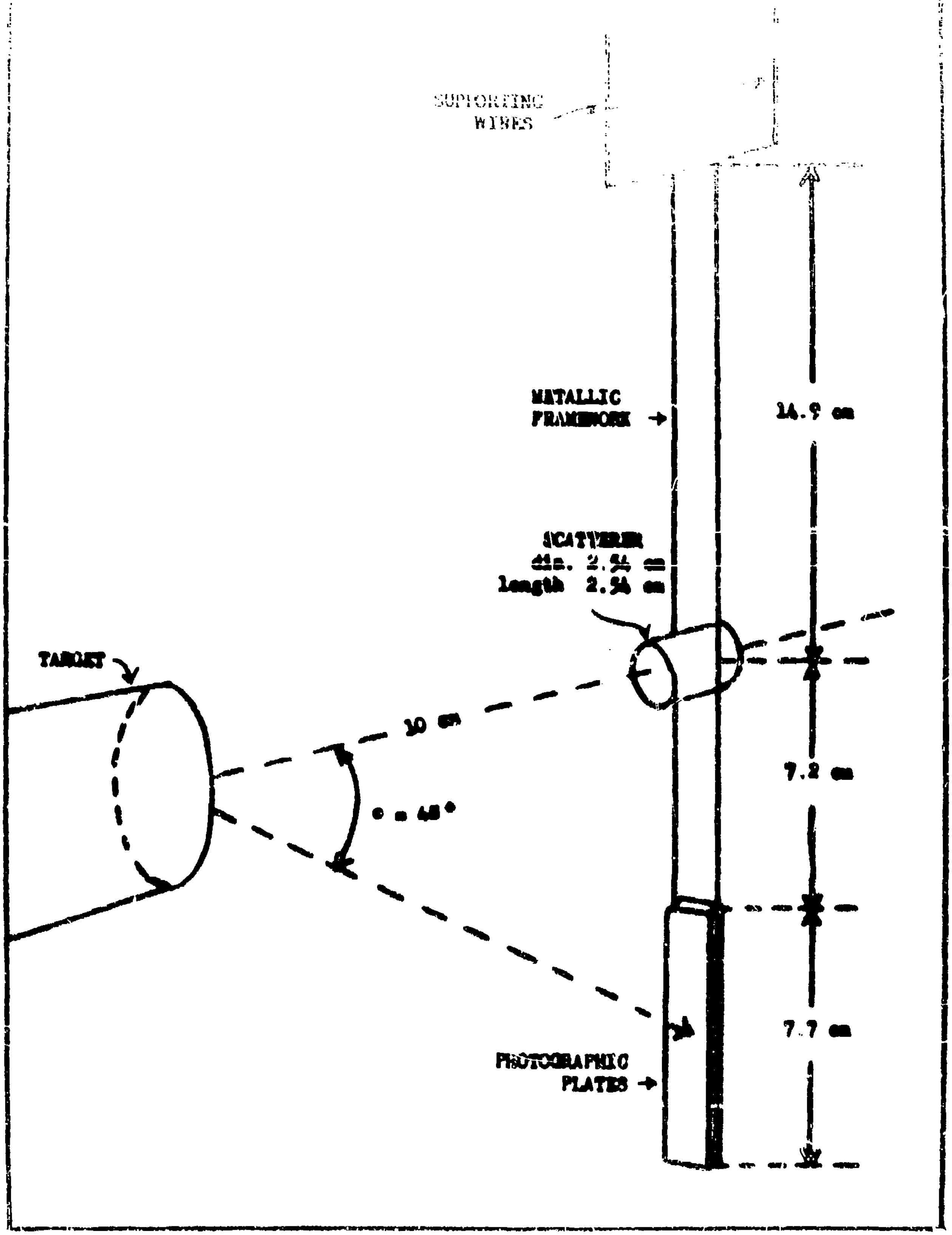


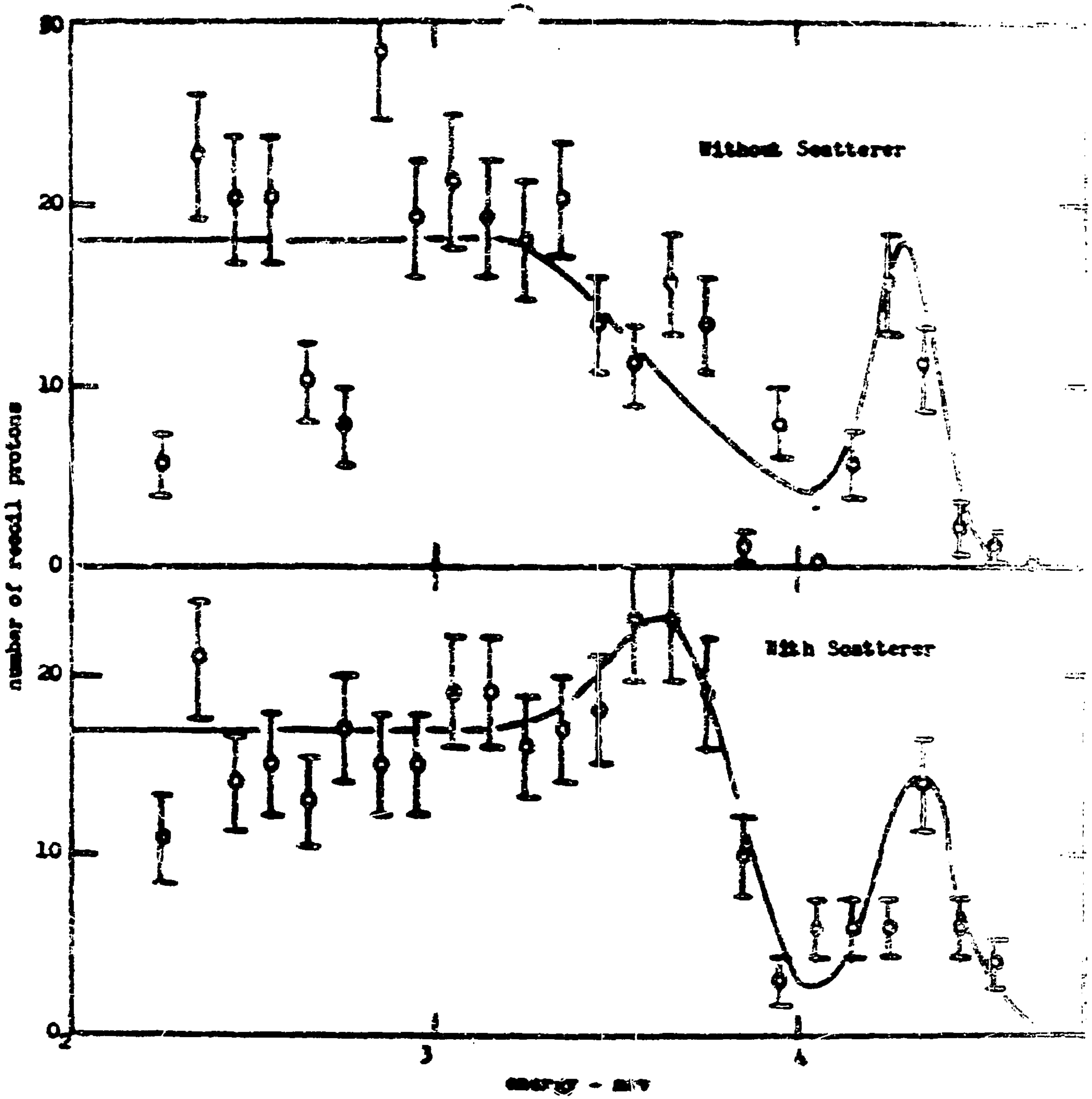
Fig. 1 SCHEMATIC DRAWING OF SCATTERING ARRANGEMENT

half nearer the scatterer, was read. In the geometry of Figure 1, recoil protons can appear which make an angle of as little as thirty degrees with the forward direction. The complement of the angle indicated in the drawing of Figure 1 is 42°. An acceptance angle of twelve degrees of the forward direction was employed in the photographic plates so that at the center of the photographic plate it would be possible to find acceptable recoil protons making an angle as small as thirty degrees with the path of the incident associated neutron coming directly from the target. The energy of the recoil proton would be given by

$$E_p = E_n \cos^2 \theta$$

where as indicated above, θ could be as little as thirty degrees, so that the recoils could have as much as three-fourths of the primary neutron energy. Since only the upper half of the plates were read, the angle was usually greater than 30°. In the measurements of this section of the report, deuterons of energy 1.3 Mev were passed through a nickel foil of thickness $\sim$ 300 Kev into a target of deuterium gas about 200 Kev thick. The resultant neutrons had an energy of $\sim$ 4 Mev as indicated by a control plate placed at the position of the scatterer. Most of the recoil protons resulting from direct irradiation of the plates were removed by choosing only recoil protons of energy in excess of 2.3 Mev. Another source of recoil protons is neutrons proceeding directly from target to plates to be scattered from the AgBr of the emulsion and from the silicon in the glass backing of the emulsion. Extensive calculations were performed to get an estimate of this effect, and they seemed to indicate that about four or five times as many neutrons are scattered from the Ag, Br, and Si as from the iron scatterer itself. This fact alone places in doubt any results which might be obtained from the unshielded geometry of Figure 1. Nevertheless, to obtain a complete experimental picture, a cylindrical iron scatterer of length one inch and diameter one inch was irradiated in the geometry of Figure 1.

A rotational method of exposure was adopted in which a total of five million integrator counts were recorded at the deuterium target of the Van de Graaff generator, two million with scatterer, two million without scatterer, and one million with a control plate in the position normally occupied by the iron scatterer to determine the homogeneity of the primary incident beam of neutrons at 4-Mev. (The calibration of the integrator is 0.05 coulomb per integrator count.) The data with and without scatterer are plotted in Figures 2 and 3, Figure 2 in energy intervals of 0.1 Mev and Figure 3 in intervals of 0.2 Mev. A continuum of recoils appears to be present below 4 Mev. The two curves are dissimilar between 3.3 and 4 Mev, suggesting the possibility that elastically and inelastically scattered neutrons have been contributed by the iron



Without Scatterer
With Scatterer
number of recoil protons
energy - mev

Fig. 2

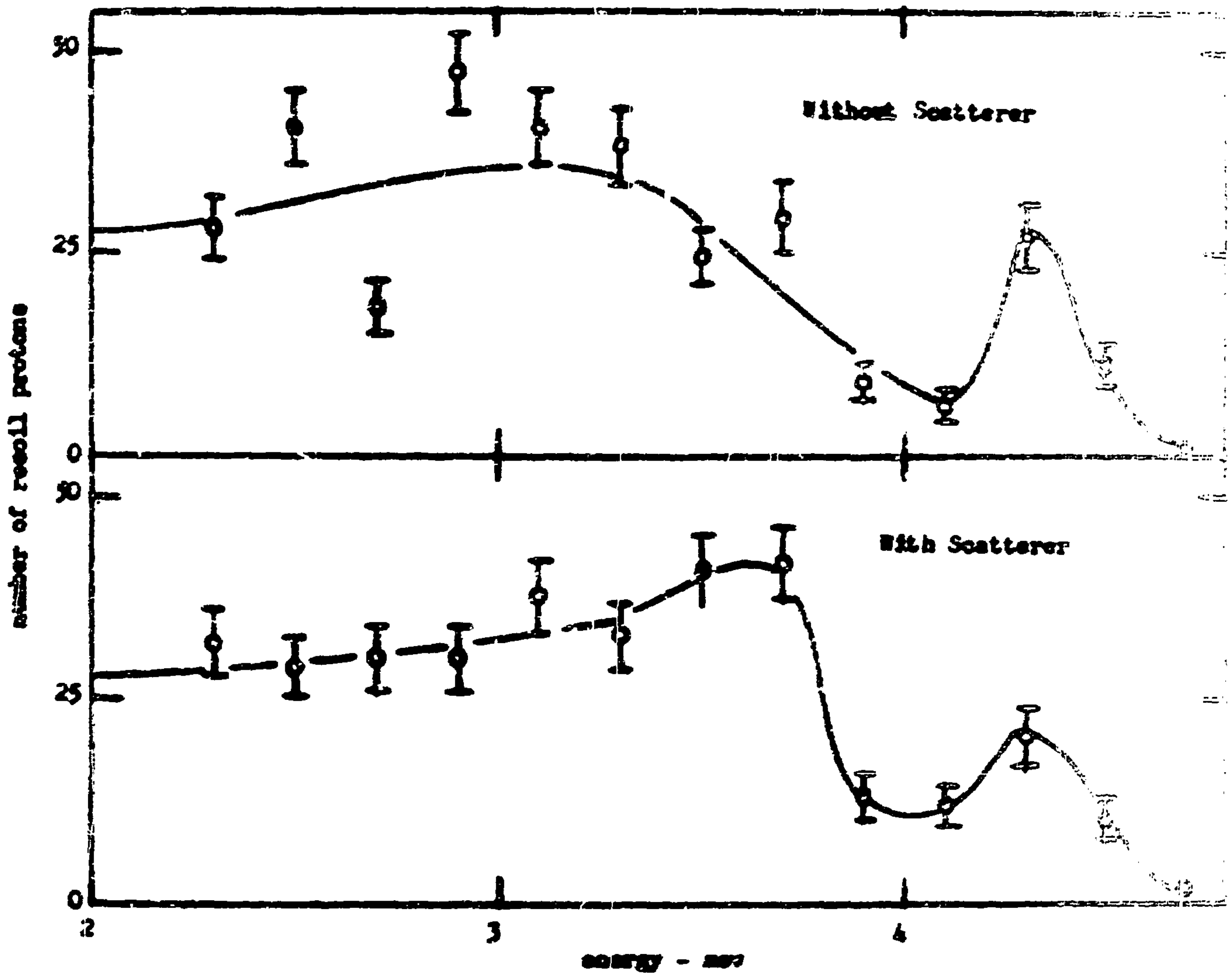

Without Scatterer
With Scatterer
number of recoil protons
50
25
0
50
25
0
2
3
4
energy - mev

Fig. 3

scatterer in this region. At ~4.3 Mev appears a group of neutrons on both sets of plates, beyond the position in energy which is possible according to the kinetics of the deuteron - deuterium reaction. This group of neutrons is assigned to the reaction N^{14} (n,p) C^{14}. When a photographic plate is placed parallel with a neutron beam, the group of neutrons from N^{14} (n,p) C^{14} is not usually noticeable. It is usually completely overshadowed by the neutrons from the D-D reaction. However, when the plates are nearly vertical to neutron beam as are those in Figure 1, the primary neutrons disappear, and the N^{14} (n,p) C^{14} neutrons become apparent.

Since the direct neutrons were so scattered by the AgBr and Si as to partially mask the contribution of the iron scatterer, it became evident that adequate shielding must be interposed between the deuterium target and the photographic plates. The decision as to how much shielding can be employed presents a problem, because if too much is placed between the target and plates, the scatterer will be too far removed from the neutron source, thus reducing the solid angle subtended at the source by the scatterer. Consequently, a survey of possible geometries was carried out with a view to observing the background of scattered neutrons in the plates under various conditions of shielding. By scattered neutrons in this case is meant those scattered from the AgBr and Si. No iron scatterer was present. No directional criteria were applied in measuring the tracks. In fact, they were not actually measured but merely counted. The number of tracks of all types per field of view was recorded. Any tracks which could be differentiated from the background grains was counted. Thus, the background measurements of the various geometries should be applicable to counter measurements as well as to photographic plates.

The various types of shields are described in Figure 4 (10 cm of paraffin, 10 cm of bismuth), Figure 5 (20 cm of paraffin), and Figure 6 (a Stelson-Preston type collimator of length 20 cm). The results of the shielding measurements are described in Figure 7, where a table of data is presented. From the table it is clear that the paraffin wedge of length 10 cm allows a background only 1.6 times as great as the collimator and that the 20 cm wedge gives rise to a lower background than the scatterer*.

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* At the bottom of the table is a row of data relating to an unshielded bombardment of a pellicle (an emulsion 300 microns thick without any glass backing). The geometry was that of Figure 1 with no scatterer present. According to the table, 16.8 tracks per field of view were observed. This figure must be divided by three to reduce the pellicle thickness to that of the photographic plates (100 microns), giving 5.6 tracks per field of view, in agreement with 5.5 tracks found in the plates. Thus, the additional 200 microns of emulsion thickness containing AgBr contribute as many

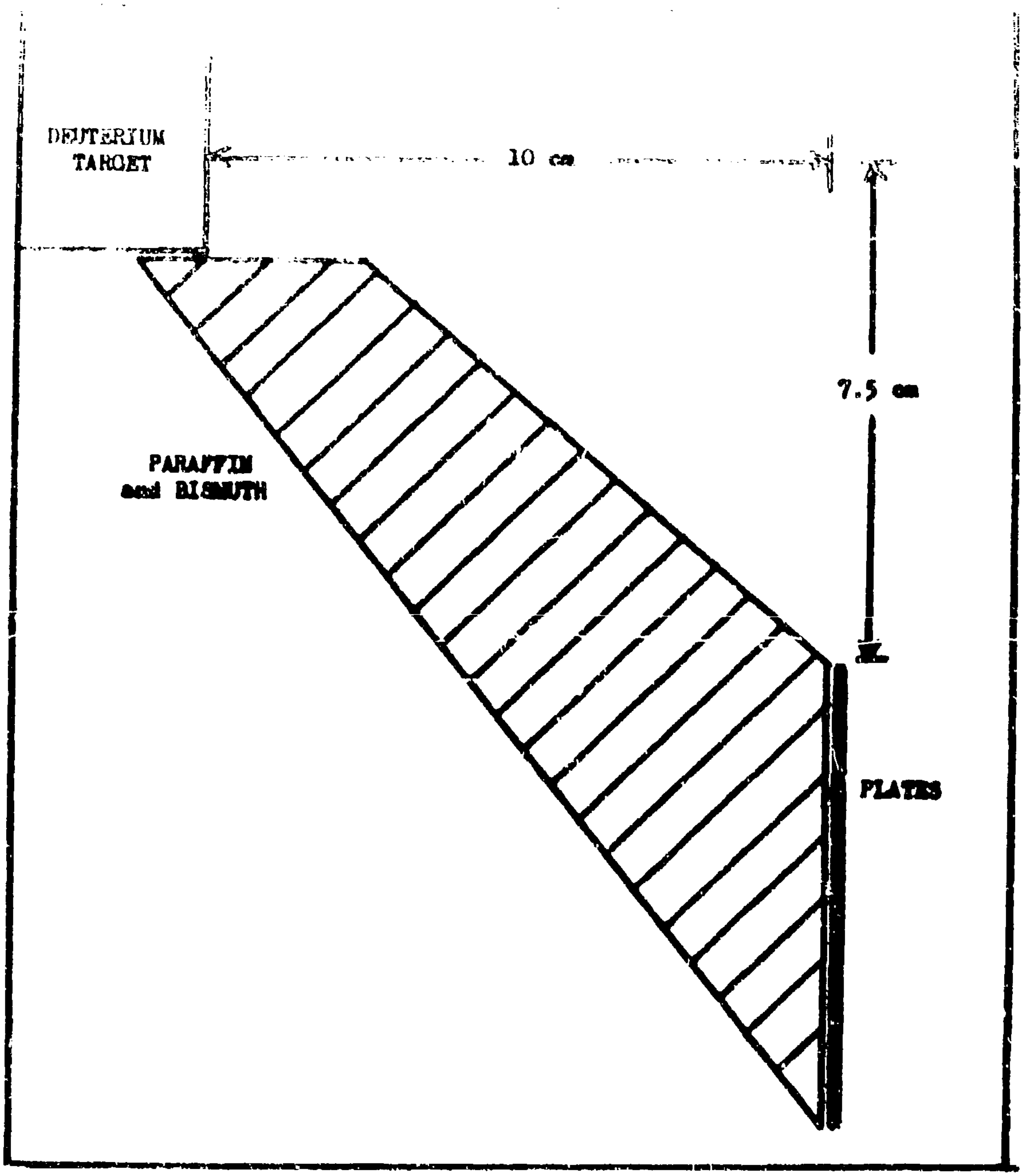


Fig. 4

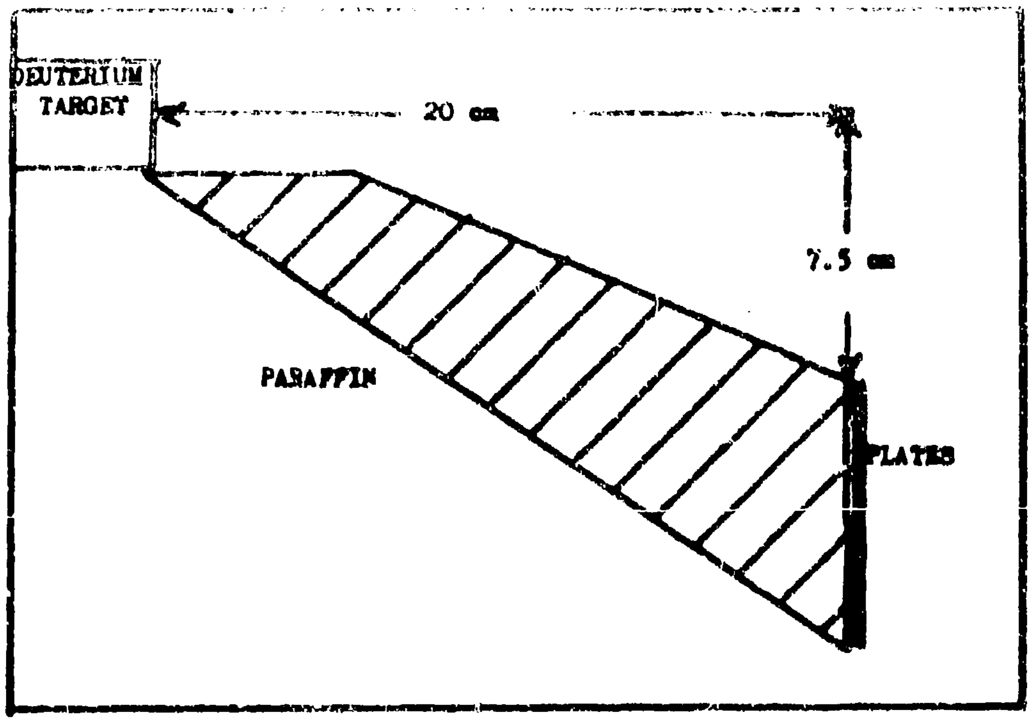


Fig. 5

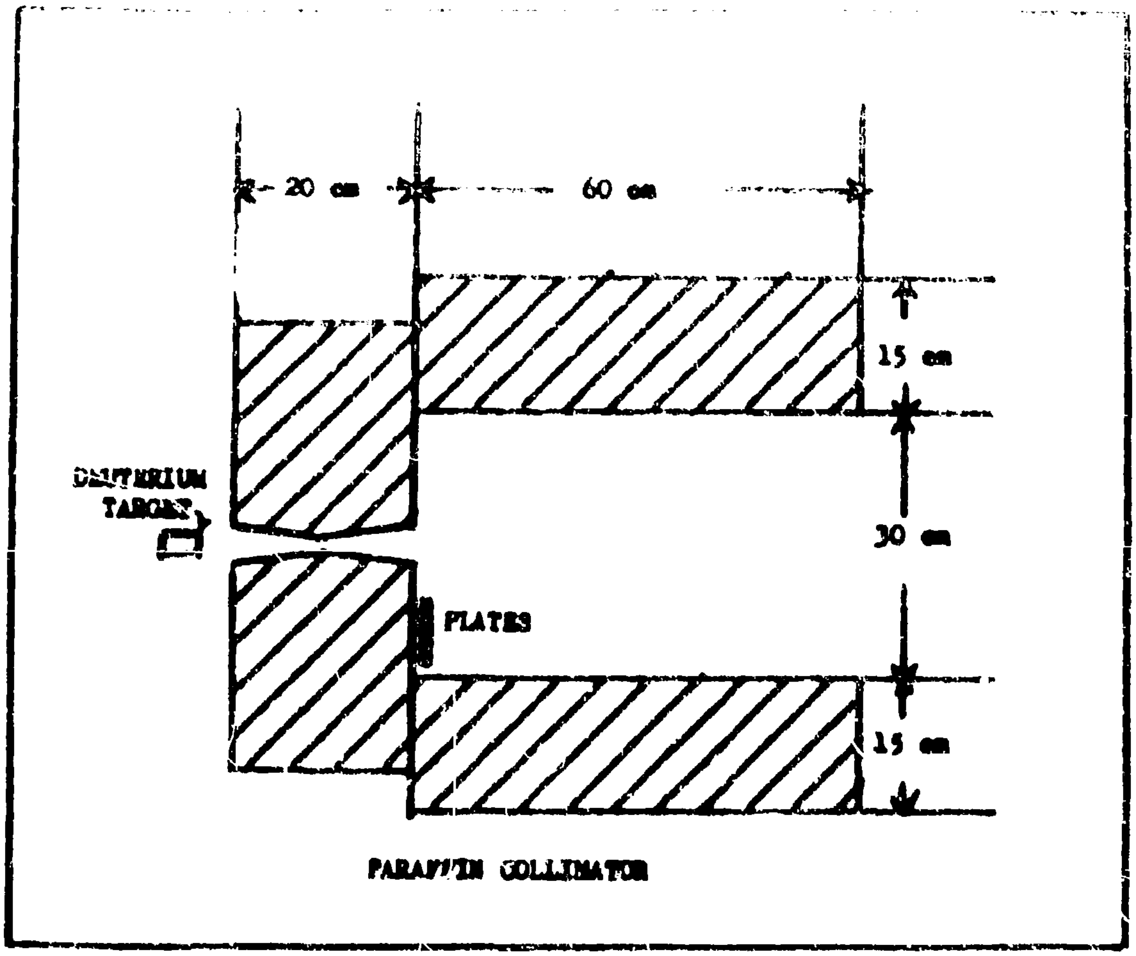

20 cm
60 cm
15 cm
30 cm
15 cm
DEUTERIUM
TARGET
PLATES
PARAFFIN COLLIMATOR

Fig. 6

PLATE NO.	SHIELD	NO. OF TRACKS	NO. OF FIELDS	TRACKS PER FIELD	TRACKS PER FIELD PER 10^5 INT. CNTS.	CORRECTED FOR SOLID ANGLE	NORMALIZED TO 100%
4	None	225	41	5.5	14.3	3710	100
6	Small Paraffin	219	70	3.2	2 77	615	16.5
7	Large Paraffin	75	100	0.75	0.78	403	10.9
9	Bismuth	183	50	3 7	4.25	945	25.5
12	Collimator	75	78	0.96	0.75	563	15.2
Pellicle	None	370	22	16.8			
		CORRECTED FOR THICKNESS		5.6	13 2	3420	92

Figure 7

scattered neutrons to the remaining 100 microns of pellicle thickness as does the glass backing to the 100 micron emulsion of the photographic plate.

In order to obtain a high density of incident neutrons, a decision was made to employ a modification of the 10 cm of paraffin shown in Figure 4. This new form of the 10-cm geometry is shown in Figure 8. The various angles of the momentum relationship are such that only one-fourth of the incident neutron energy can be imparted to a proton in the emulsion. However, only recoils of energy greater than 1.6 Mev were actually accepted. The energy distributions with and without scatterer and the difference curve are plotted in Figure 9. An elastic group is well defined, but the inelastic one is "smeared" over a considerable region and does not exhibit particularly good definition. The broken line of the difference curve represents the energy distribution corrected for variation with n-p scattering cross-section and acceptance probability of the tracks.

To obtain the data of Figure 9, 10,380 fields of view were observed in binocular microscopes to obtain 779 acceptable recoil proton tracks in the case of scatterer present. The background without scatterer was determined by measuring 323 tracks in 5,650 fields of view. As to bombarding time, a total of seven million integrator counts were accumulated with scatterer and seven million without scatterer. A control plate replaced the scatterer for one million integrator counts

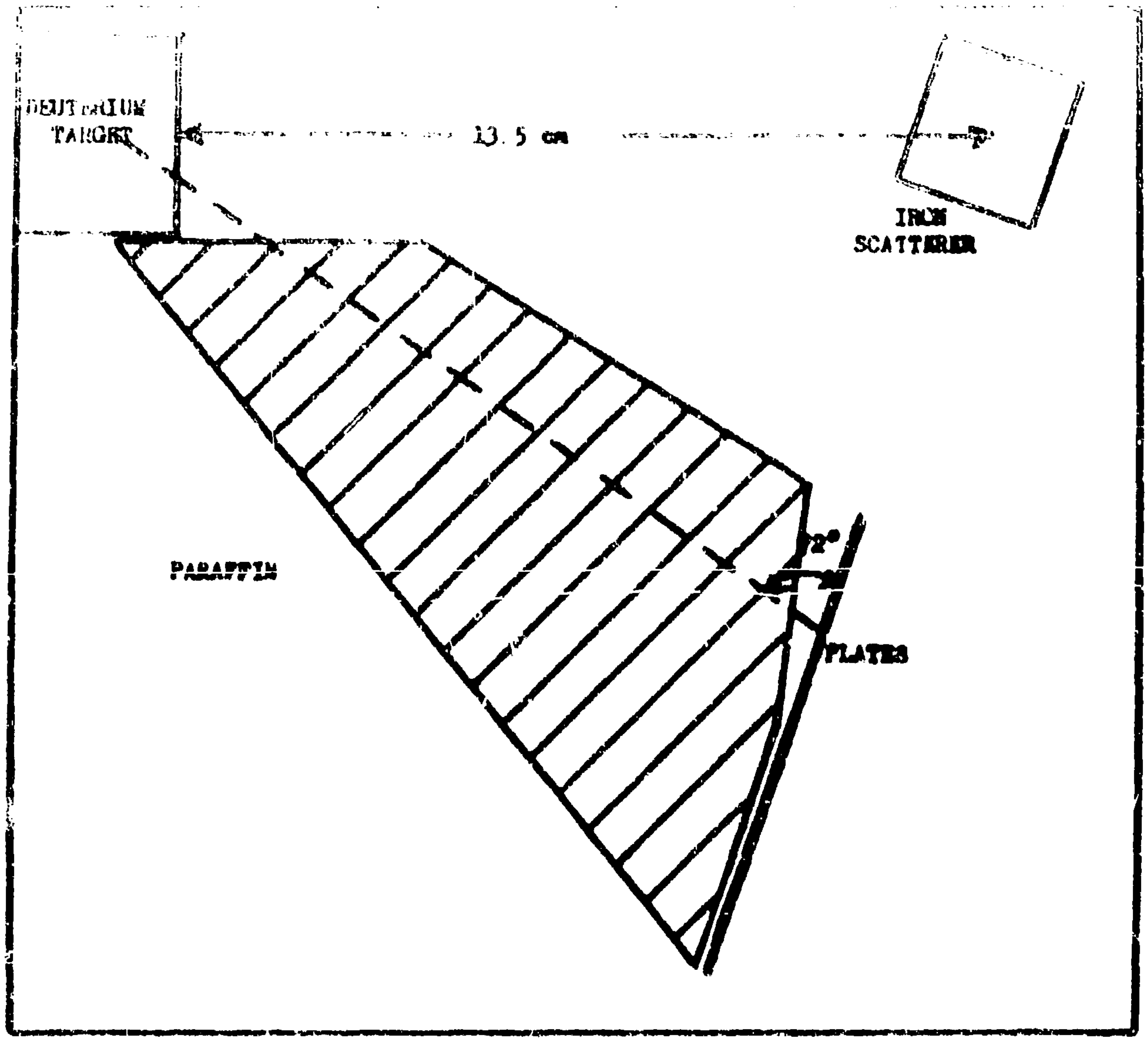
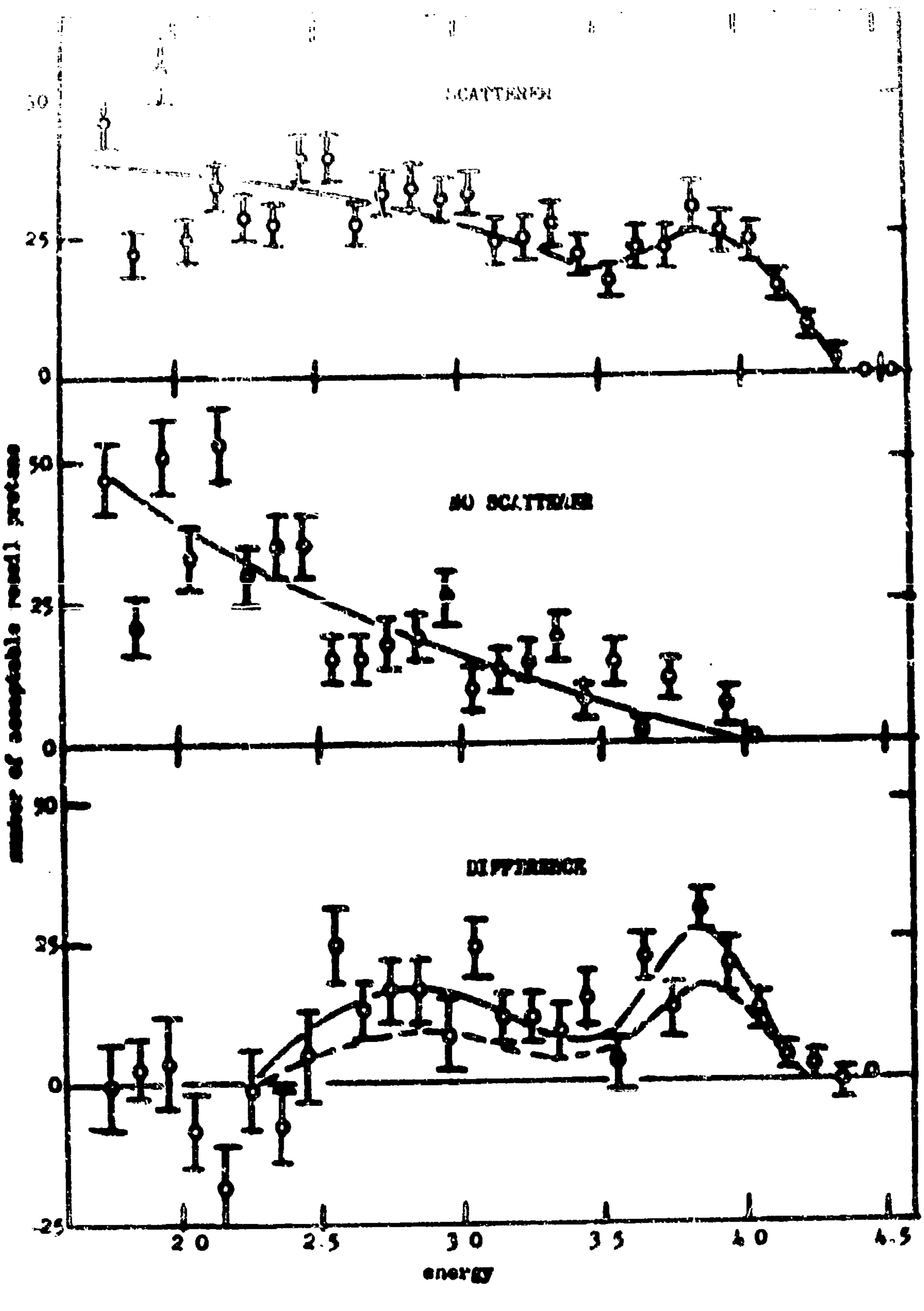


Fig. 8



SCATTERER
NO SCATTERER
DIFFERENCE
number of acceptable recoil protons
energy

Fig. 9

to obtain the energy spectrum of the primary beam of neutrons employed in the scattering experiment. It is possible that some of the neutrons from the target could be scattered and degraded in the paraffin, then elastically scattered in the iron to the photographic plates to appear as a low energy group to be confused with inelastically scattered neutrons from the iron scatterer. A background "run" does not take into account neutron groups produced in this manner. The primary neutron spectrum is shown in Figure 10. It is estimated that less than five per cent of the neutrons lie below the principal group. The presence of the smeared inelastic contribution of the difference curve of Figure 9 cannot be explained by such a small percentage of degradation of the primary beam.

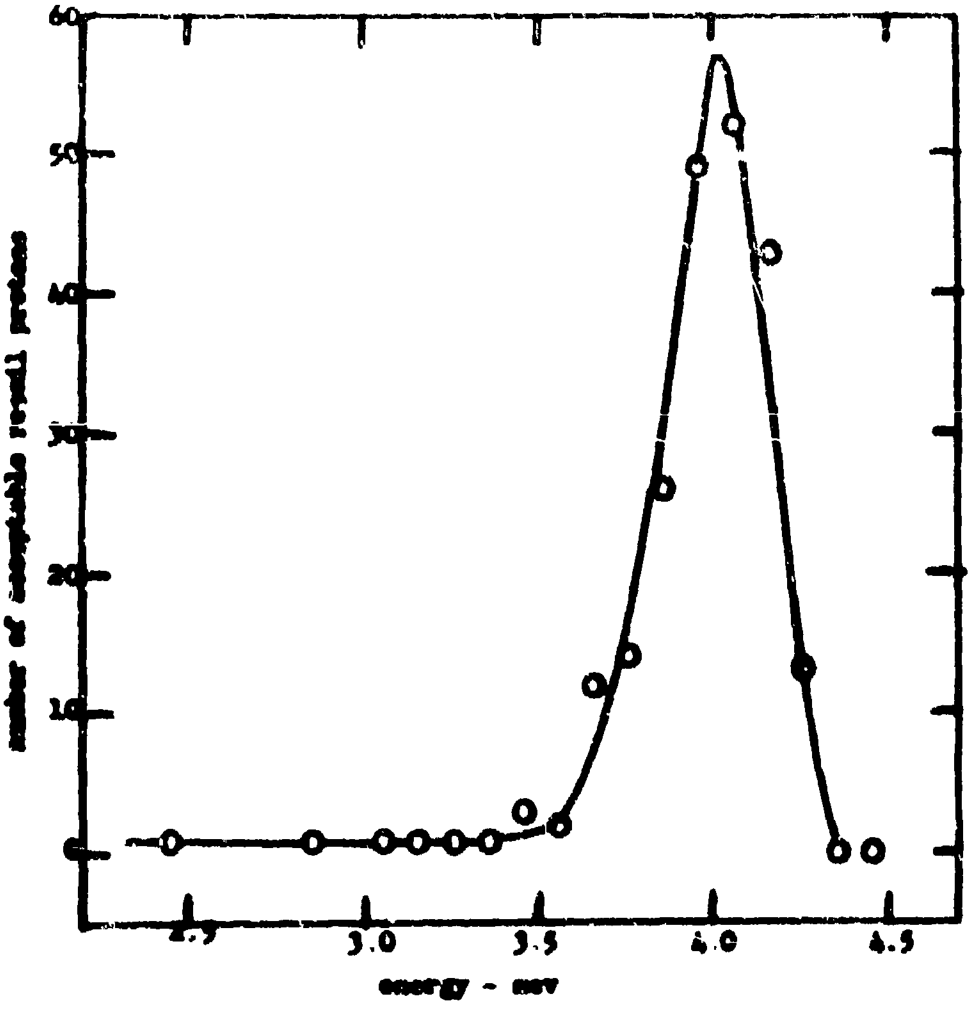


Fig. 10

Introduction

Previous measurements[1] of the total cross section of

[1] R. K. Adair, Rev. Mod. Phys. **22**, 249 (1950).

phosphorus for fast neutrons have yielded only scanty information in the energy range available to us. The total cross section for chlorine has not been reported previously, while that for gold appeared in abstract form[2] during our investigation.

[2] R. L. Becker, M. Walt and A. Okazaki, Bull. Amer. Phys. Soc. **27**, 19 (1952).

Apparatus

A radio frequency ion source has recently been installed in our small electrostatic generator, which together with suitable auxiliary focusing voltages yields a 15 μ.a. resolved beam of protons in the energy range 500 to 1600 Kev. The generator voltage is kept constant to within 1 to 2 kv by the use of a corona stabilizing circuit whose error signal is derived from a pair of insulated slits located at the output end of the analyzing magnet.

In order to measure the ion beam energy, work was initiated on a torsion balance with which the magnet field of the analyzing magnet could be measured. Development work was under way at the time of these experiments, and the necessary stability and reproducibility of the torsion balance was achieved. However, since the completion of this work would have required more time than could reasonably be allotted to these experiments, it was decided to rely on the existing generating voltmeter. A careful investigation of the stability and reproducibility of the generating voltmeter revealed that after certain difficulties in the grounding of the rotor were eliminated, the only remaining variable was the temperature expansion of the generator column. When this was reduced as far as possible by the use of water-cooling coils on the pressure tank, the reproducibility of the generating voltmeter was generally about 2 Kv. Thus, while the voltmeter left much to be desired, it was adequate for the present experiments, and was then calibrated, using the $F(p;\alpha,\gamma)$ resonance at 873.5 Kev, the $Al(p,\gamma)$ resonance at 995.3 Kev and the $H^3(p,n)$ threshold at 1.019 Mev[3,4]. In addition the $H^3(p,n)$

3) R. H. Herb, S. C. Snowdon, and O. Sala, Phys. Rev. 75, 246 (1949)

4) R. F. Taschek, G. A. Jarvis, H. V. Argo and A. Hemmendinger, Phys. Rev. 75, 1268 (1949).

threshold was checked after each 100 Kev interval throughout the cross section measurements.

The tritium targets were prepared by absorbing tritium gas at [illegible] mm Hg pressure into a zirconium film evaporated onto a wolfram backing[5]. Some difficulty was encountered in making

5) A. B. Lillie and J. P. Conner, Rev. Sci. Inst. <u>22</u>, 210 (1951).

uniform zirconium-tritium targets, as evidenced by the presence of fluctuations in the neutron counting rate of about two or three times the statistical fluctuations. To remove this source of trouble, two pairs of crossed electrostatic deflecting plates were installed just after the output slits of the analysing magnet. A 60 cycle per second a.c. voltage was applied across one pair of plates, and a 400 cycle per second a.c. voltage was applied across the other pair of plates, in order to spread out the beam over the diaphragms near the target.

The target area was suitably diaphragmed to allow suppression of the secondary electrons from the target and thus, permit the use of a beam current integrator in order to monitor the neutron yield. A conventional condenser and neon-glow tube was used in conjunction with a scale of 256 scaler for measuring the total charge accumulated on the target during each run.

The neutrons were detected by a conventional enriched $B^{10}F_3$ slow neutron counter[6] surrounded by paraffin with an outer

6) Manufactured by N. Wood Counter Laboratory, 5491 Blackstone Avenue, Chicago 15, Ill.

layer of cadmium. The outside dimension of the counter with paraffin was 4 inches and its effective length was 6 inches. Two checks of the stability of the neutron detector and its associated circuitry, using a 10 millicurie Ra-Be source, showed that electronic jitter and voltage drifts did not influence the counting rate more than one per cent.

Finally, there was present in all the measurements a time dependent background of neutrons coming mainly from the region of the analysing magnet chamber. This was reduced considerably by interposing a stack of five gallon cans filled with a saturated water solution of borax. In addition, the counting rate of these background neutrons was determined at frequent intervals while taking the data, and an attempt was made to correct the desired neutron counting rate for this source of neutrons. Since the amount of these background neutrons was never more than five per cent, it is felt that this source of fluctuation is adequately accounted for.

Experimental

Before measuring the total neutron cross sections, the effect of the exact location of the scatterer was investigated. Figure 11 shows that the location of the scatterer along the target-detector axis is not very critical, and that the scattering-in correction can account for the observed variation of the counting rate. As the scatterer is moved nearer to the neutron source, the counting rate rises sharply,

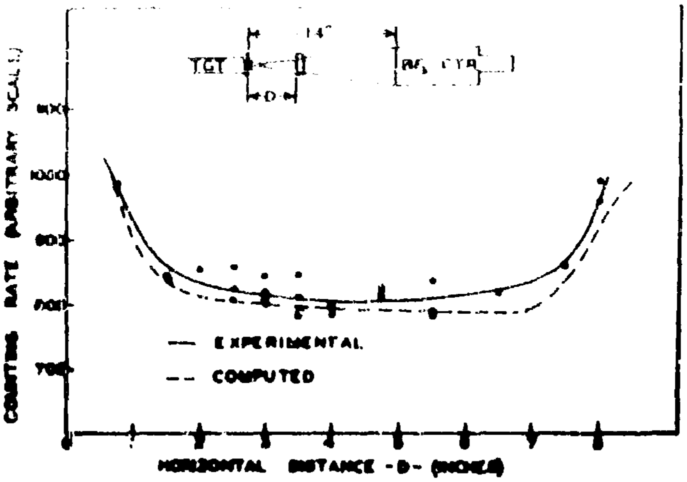


Fig. 11. Counting rate of neutron counter versus the distance of the gold scatterer from the target along the target-detector axis. The solid line is the average of the experimental points. The dashed curve was computed using the following parameters: counting rate without scatterer - 1317, shadow cone background -1.50, cross section at 1.13 Mev—[illegible] barns, counter diameter —1.00 inches, target-detector distance—16 inches.

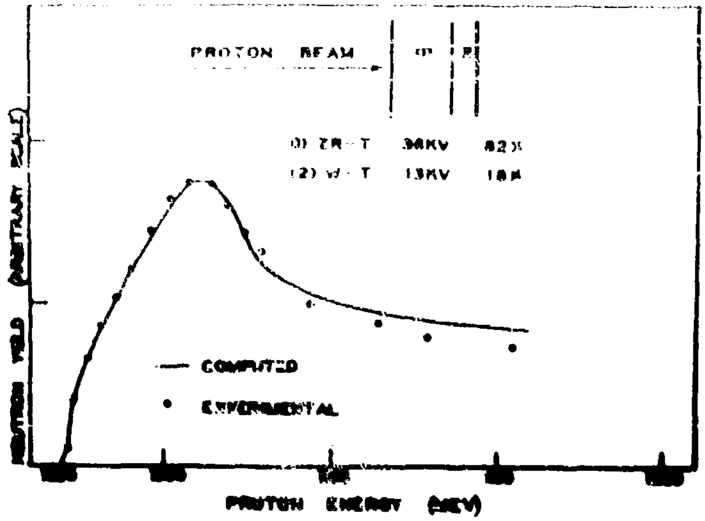


Fig. 12. Yield of neutrons in the forward direction from the $H^3(p,n)He^3$ reaction. The solid curve was computed by adding the yield predicted for a 36Kev thick target containing 82 percent of the tritium to the yield curve predicted for a 13Kev thick target containing 18 percent of the tritium, but displaced in energy by 36 Kev. The algebraic details are given in the appendix.

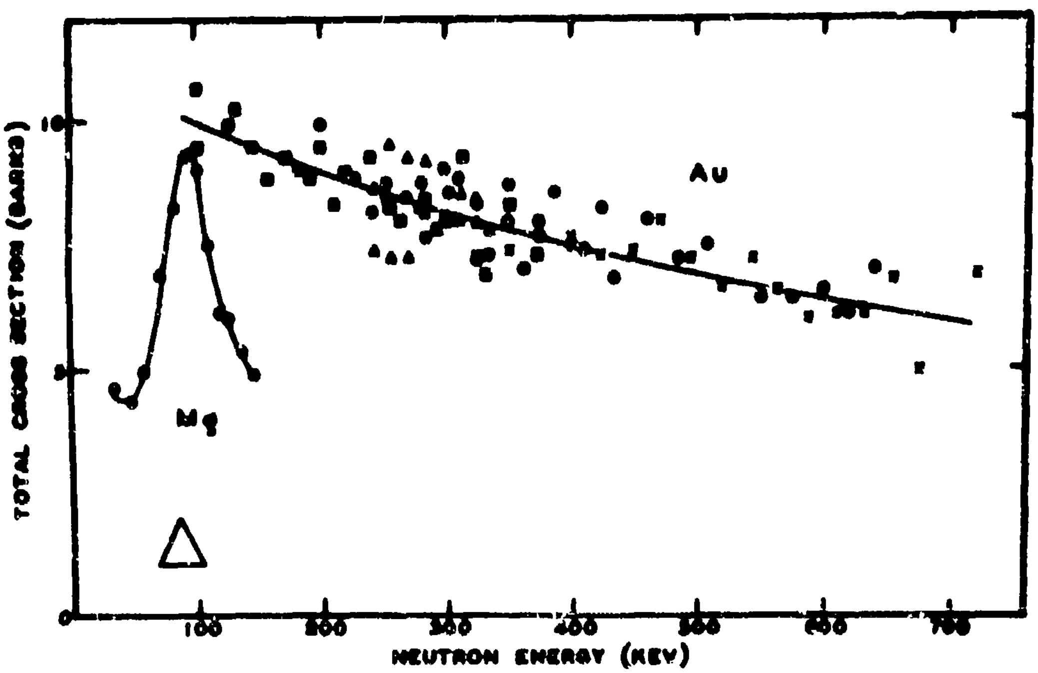


Fig. 13. Total cross section of gold for neutrons in the energy range 100 - 250 Kev was measured with the detector 60° from the direction of the proton beam. The total cross section of magnesium was also measured in the 60° geometry.

and may be accounted for by the rapid increase of the solid angle subtended by the scatterer from the target. If the scatterer is moved toward the neutron counter, a sudden increase in counting rate occurs because in our set-up the diameter of the counter is larger than the diameter of the scatterer. As the scatterer passes inside the detector-cone, some neutrons pass directly into the detector without passing through the scatterer. The entire effect can be computed from the parameters given in the caption to Figure 11. Hence, it was felt that the correction due to the scattering of neutrons into the detector are adequately accounted for by the following formula:

$$\sigma n d = \ln \left[(1 \cdot f/(N/N_0 - f) \right] \qquad (1)$$

where σ is the total cross section, $\underline{n}$ is the number of scattering nuclei/cm^3, $\underline{d}$ is the thickness of the scatterer, $\underline{N}$ is the counting rate with the scatterer in place corrected for the paraffin shadow-cone background, N_0 is the counting rate without the scatterer corrected for the shadow-cone background, $\underline{f}$ is a geometrical measure of the scattering-in correction and is given by

$$f = \left[(4\pi\ /\sigma) \ \ (d\sigma/d\omega \ \right] \cdot \left[(L/r)^2 \cdot \ A\ /\ 4\pi\,(L-r)^2 \right] \quad (2)$$

where $d\sigma/d\omega$ is the differential cross section in the direction of the detector, $\underline{L}$ is the target-detector distance, $\underline{r}$ is the target scatterer distance, and A is the area of scatterer. The first bracket was taken equal to unity, since it is not exactly calculable but is expected to be near unity in our energy range according to the continuum theory of nuclear reactions[7]. In the geometry used, the scattering-in

7) Final Report of the Fast Neutron Data Project, NYO-636.

correction, f, usually amounted to four per cent.

The variation of the neutron counting rate as the scatterer was moved in a plane perpendicular to the target-detector axis was also investigated. A misalignment of about one-half inch gave a negligible change in the counting rate provided that the scatterer was aligned initially.

The energy spread of the neutrons was determined almost entirely by the thickness of the zirconium-tritium target. In order to measure this target thickness, careful measurements of the neutron yield in the forward direction were taken (see Figure 12). In the Appendix the shape of the yield curve to be expected was calculated using several reasonable assumptions. If only one uniform target was employed, a departure of the experimental points from the calculated curve was observed in much the same fashion as that described by Bonner and Butler[8]. If,

8) T. W. Bonner and J. W. Butler, Phys. Rev. 83, 1091 (1951).

however, two different target layers were assumed to constitute the target, then much of the discrepancy was removed. In particular, if 82 per cent of the tritium was assumed to be present in a 36 Kev layer, and directly in back of this, 18 per cent of the tritium was assumed to be present in a 13 Kev layer, then a unique fit was obtained within the accuracy of the assumptions involved. The second layer is thought to be due to an absorption of the tritium in the wolfram backing onto which the zirconium was evaporated. In any case, the neutron energy spread is seen to be due to a 40-45 Kev thick target.

As a check on this, the narrow resonance in the total neutron cross section of magnesium at 85 Kev reported by Fields and Walt[9] was measured with our source of neutrons.

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9) R. E. Fields and M. Walt, Phys. Rev. <u>83</u>, 479 (1951).

Figure 13 shows the observed neutron energy width to be 45-50 Kev in agreement with the target thickness prediction.

Data

The gold scatterer consisted of a one-half inch thick cylinder of pure gold 1 3/4 inches in diameter. Figure 13 gives the results for gold, and it is to be noted that these data were taken before installing the beam-spreaders and the water-can absorbers. A comparison of the gold data with either the chlorine or phosphorus data shows the extent of the reduction in the fluctuations affected by the use of the beam spreaders and the water cans. Several check points were made on gold after the spreaders and the water cans were installed, and these repeat points fell right along the average line drawn through the points. From these results, it is felt that the total cross section for gold does not have resonances in the energy range 100 to 700 Kev. Furthermore, the magnitude of the cross section agrees well with those of neighboring atomic weight elements.

The total cross section for chlorine was measured using CCl_4 in a 1 3/4 inch diameter cylinder, 2 inches in length. The effect of the carbon was subsequently subtracted, using the carbon cross section given by Adair[1)]. Indications of resonances occur at several neutron energies and are separated by about 100 Kev.

The total cross section for phosphorus was measured, using white phosphorus cast into a 1 3/4 inch diameter cylinder, 1 1/2 inches in length. There are several prominent resonances in this energy range, but higher resolution experiments which we hope to be able to carry out probably are needed to give any details concerning the nature of the resonances. The average value agrees well with that reported by Adair[1)].

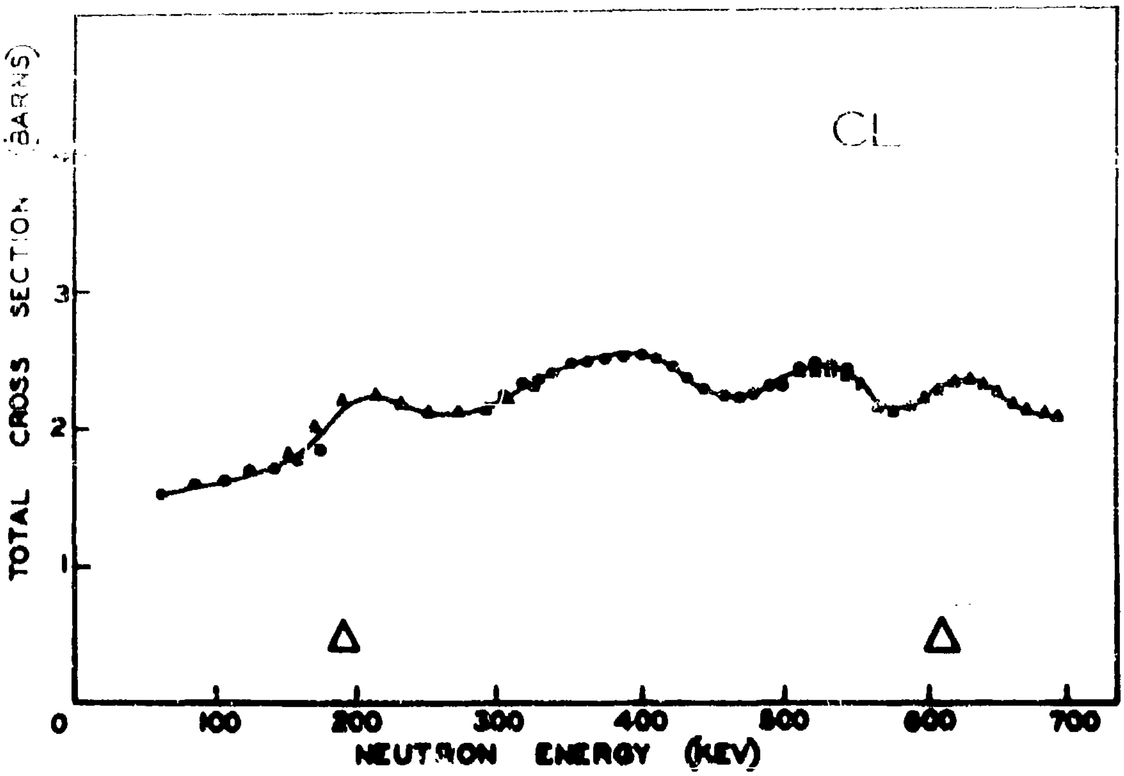

Fig. 14. Total cross section of chlorine for neutrons in the energy range 100 - 700 Kev. The range 100 - 230 Kev was measured in the 60° geometry.

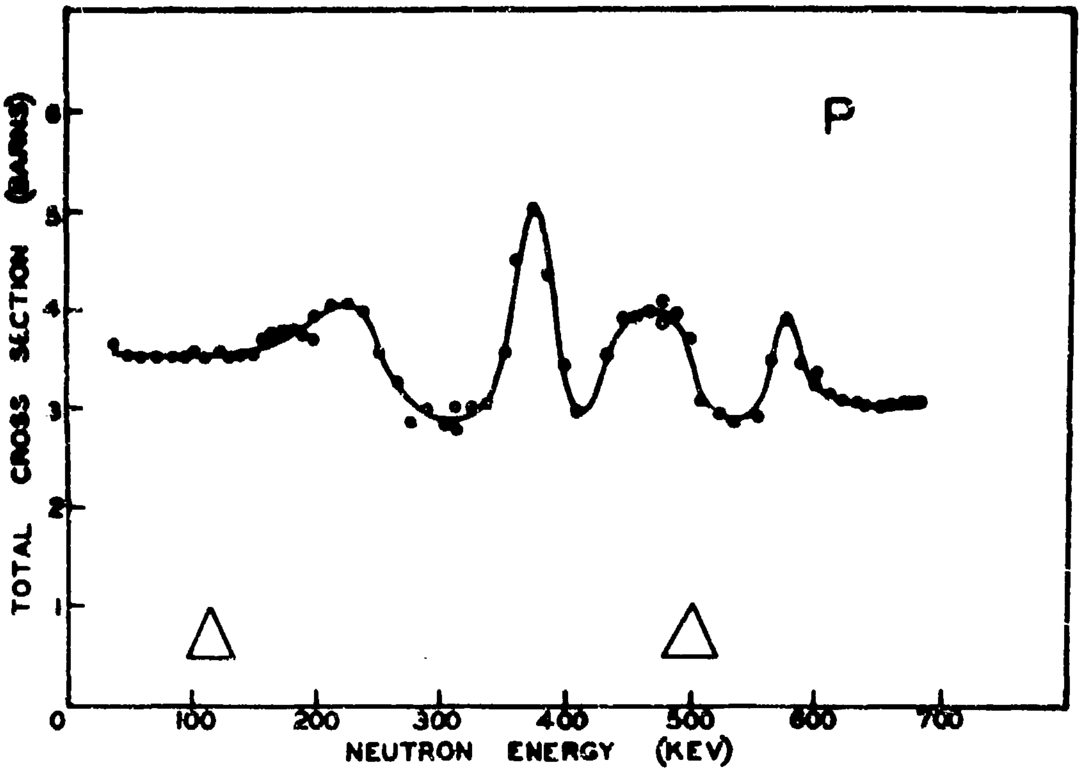

Fig. 15. Total cross section of phosphorous for neutrons in the energy range 100 - 700 Kev. The range 100 - 250 Kev was measured in the 60° geometry.

Appendix

The forward direction yield of the $H^3(p,n)He^3$ reaction from a target of finite thickness as measured by our finite-sized counter (assumed to be a flat circular disk) is given by

$$Y = (N_o n/4\pi)\iint \eta(\theta)\sigma(E)\ (d\Omega\phi_1/d\Omega_\theta + d\Omega\phi_2/d\Omega_\theta)\ d\Omega_\theta\ dx,$$

where N_o is the number of protons striking the target per second, n is the number of tritium nuclei per cubic centimeter, θ is the laboratory angle measured from the proton beam direction, ϕ_1 and ϕ_2 are the two center of mass angles from which emergent neutrons contribute to the laboratory solid angle $d\Omega_\theta$ and $\eta(\theta)$ is the zonal efficiency of the detector. The differential cross section in laboratory co-ordinates has been calculated with the assumption that the differential cross section in the center of mass co-ordinates is a constant. The total cross section, $\sigma(E)$ is then only a function of the energy of the proton E in the layer, dx, of the target.

For convenience in integration, a parameter

$$k = (M_T M_R / M_B M_O)^{1/2}\,(1 - E_O/E)^{1/2}$$

is introduced where M_T, M_R, M_B and M_O are the masses of the target, residual, bombarding and outgoing particles respectively.

E_o is the threshold energy of the reaction in laboratory co-ordinates. The total cross section of the reaction is assumed to vary as $(E - E_o)^{1/2}$ near threshold and since the exact variation above threshold is not known, it is chosen for convenience in integrating to be such that $\sigma dx \sim k^2 dk$. The zonal efficiency of the counter $\eta(\theta)$ is also assumed to be a constant.

Using the dynamics of the $H^3(p,n)He^3$ reaction, the value of $d\Omega_\phi / d\Omega_\theta$ may be found as a function of k and θ. The integration then may be carried out with the result that

$$Y = (N_o nA/3a)\ K_1^2 \quad \text{for} \quad 0 < K_1 < \sin\theta_o .$$

$$Y = (N_o nA/3a)\left[K_1^3 - \cos\theta_o\,(K_1^2 - \sin^2\theta_o)^{3/2}\right]$$

$$\text{for } \sin\theta_o < K_1 < (M_R M_T / M_p M_o)^{1/2}\left[1 - E_o/(E_o + at)\right]^{1/2},$$

$$Y = (N_o nA/3a)\left[K_1^3 - K_2^3 - \cos\theta_o\,(K_1^2 - \sin^2\theta_o)^{3/2}\right] \text{ for } 0 < K_2 < \sin\theta_o$$

$$Y = (N_o nA/3a)\left[K_1^3 - K_2^3 - \cos\theta_o\,(K_1^2 - \sin^2\theta_o)^{3/2} + \cos\theta_o\,(K_2^2 - \sin^2\theta_o)^{3/2}\right] \text{ for } K_2 > \sin\theta_o \text{ but } K_1 \leq 1.$$

In the formulas A is an unknown constant depending on the efficiency of the counter and other constants of the reaction, a is the energy loss per cm for the proton beam in the target, θ_o is the half angle subtended by the counter (7.50^o) and t is the thickness of the target in cm. k_1 is the value of k at the front edge of the target and k_2 is the value of k at the back edge of the target, each for an incident proton beam of energy E_B.

III. INSTRUMENTATION AND FUTURE MEASUREMENTS.

The neutrons employed in the measurements of this report were generated by deuteron bombardment of deuterium in the smaller Bartol Van de Graaff generator. In the fall of 1951, this smaller generator was transferred from its previous location to the new off-campus nuclear research center of the Bartol Research Foundation. Much of the spring of 1952 was consumed in bettering the performance of the generator. For example, the bombarding beam of magnetically analysed deuterons was increased from 0.5 to 1.0 microampere to twenty microamperes facilitating infinitely the production of neutrons for measurements such as those described in Sections I and II of this report.

A Cockroft-Walton set which has been previously described (Reference 3, Section I), is being transferred to a building of its own. This building is being constructed with exclusive use of the private funds of the Bartol Foundation. Neutrons have been successfully produced in this generator, but since it was located in close proximity to the small generator, simultaneous operation of the two accelerators became impossible.

With a view to applying scintillation counter methods to detection of neutrons and gamma rays involved in scattering experiments, two complete detection units are being built.

Each consists of photomultiplier, linear amplifier, single channel pulse height discriminator, and scaling circuits. A coincidence analyzer will also be employed for noting coincidences between neutrons and gamma rays.

Using the 20-cm geometry of Figure 5, Section I, chromium has been irradiated by 4-Mev neutrons. Iron has been irradiated again in a new geometry which will be described in a later report. These exposures have been just completed at the time of writing this manuscript and the associated photographic plates have not been analyzed. It was planned also to irradiate Ni, C, and Fe in the 20-cm geometry. However, since the neutron flux is so great for 22 microamperes of million volt deuterons, the tolerance dosage was experienced in a very short time by the operating crew during the iron-chromium bombardments. It has therefore become necessary to postpone temporarily further irradiations.

It will be recalled that some time ago the large Van de Graaff generator had been built up to one-third of its final height and tested as regards voltage, beam production, and operation. The success of these tests justified the next step, the extension of the generator to its full height. This extension has been carried out and electrostatic voltages in excess of 5 MV have been obtained.

The full length of the accelerating tube has been installed, together with the ion source. Several tests relative to the ion beam are under way. In this connection, electrostatic deflector plates and the suppressor have been added just below the accelerating tube proper. The purpose of the former is to align the beam and that of the latter to suppress back electrons.

The analysing magnet is now in operating, although a few refinements are still to be made. Essentially all the energy controlling mechanism has been completed; the elements which have not been completed await the beam tests mentioned above. It is expected that, barring unforeseen circumstances, the generator will be operating with a focused beam and at a voltage in excess of 5 million volts in about a month.

The above progress report on the generator has been included because it is intended that this machine shall be used in connection with the neutron scattering work, permitting neutron beams of much higher energy and greater intensity than those so far available to us.